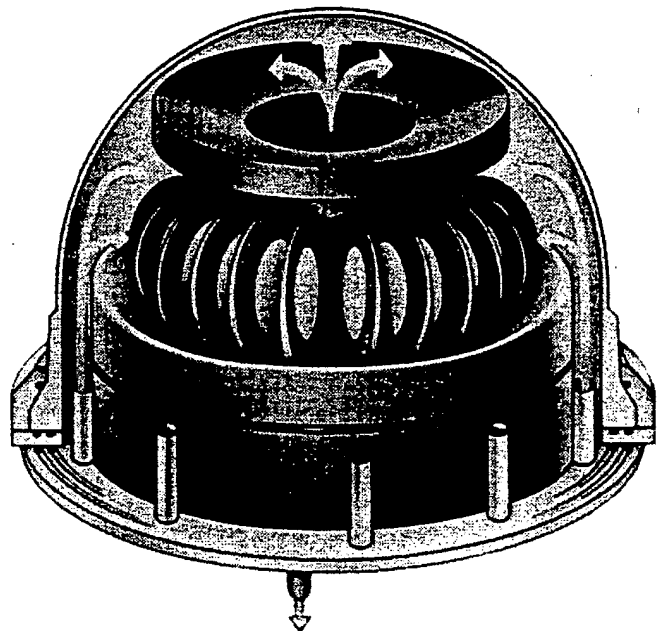


# **HANDBOOK OF THIN-FILM DEPOSITION PROCESSES AND TECHNIQUES**

**Principles, Methods, Equipment  
and Applications**



**Edited by  
Klaus K. Schuegraf**

**NOYES PUBLICATIONS**

**Appendix B**

Goldwasser *et al.*  
Application No.: 08/847,967

Copyright © 1988 by Noyes Publications

No part of this book may be reproduced or utilized in any form or by any means, electronic or mechanical, including photocopying, recording or by any information storage and retrieval system, without permission in writing from the Publisher.

Library of Congress Catalog Card Number: 87-34702

ISBN: 0-8155-1153-1

Printed in the United States

Published in the United States of America by  
Noyes Publications  
Fairview Avenue, Westwood, New Jersey 07675

10 9 8 7 6

**Library of Congress Cataloging-in-Publication Data**

**Handbook of thin-film deposition processes and techniques :**  
principles, methods, equipment, and applications / edited by Klaus  
K. Schuegraf.

p. cm.

Bibliography: p.

Includes index.

ISBN 0-8155-1153-1

1. Thin film devices--Design and construction--Handbooks, manuals,  
etc. I. Schuegraf, Klaus K. II. Title: Handbook of thin-film  
deposition processes and techniques.

TK7872.T55H36 1988

621.381'72--dc19

87-34702

CIP

**Appendix B**

Goldwasser *et al.*

Application No.: 08/847,967

---

## Contents

---

### 1. DEPOSITION TECHNOLOGIES AND APPLICATIONS:

INTRODUCTION AND OVERVIEW .....	1
<i>Werner Kern and Klaus K. Schuegraf</i>	
Objective and Scope of This Book .....	1
Importance of Deposition Technology in Modern Fabrication Processes .....	2
Classification of Deposition Technologies .....	3
Overview of Various Thin-Film Deposition Technologies .....	3
Evaporative Technologies .....	3
Molecular Beam Epitaxy .....	5
Glow-Discharge Technologies .....	5
Sputtering .....	5
Plasma Processes .....	6
Cluster Beam Deposition .....	7
Gas-Phase Chemical Processes .....	8
Reactors .....	9
Vapor-Phase Epitaxy .....	10
Photo-Enhanced Chemical Vapor Deposition (PHCVD) .....	10
Laser-Induced Chemical Vapor Deposition (LCVD) .....	10
Ion Implantation .....	11
Thermal Oxidation .....	11
Oxidation of Silicon .....	11
Other Gas-Phase Oxidations .....	11
Liquid-Phase Chemical Formation .....	11
Electrolytic Anodization .....	12
Electroplating .....	12
Chemical Reduction Plating .....	12
Electroless Plating .....	12
Electrophoretic Deposition .....	12

---

## Appendix B

Immersion Plating . . . . .	13
Mechanical Methods . . . . .	13
Liquid-Phase Epitaxy . . . . .	13
<b>Criteria for the Selection of a Deposition Technology for</b>	
<b>Specific Applications . . . . .</b>	<b>14</b>
Thin-Film Applications . . . . .	14
Electronic Components . . . . .	14
Electronic Displays . . . . .	14
Optical Coatings . . . . .	14
Magnetic Films for Data Storage . . . . .	14
Optical Data Storage Devices . . . . .	15
Antistatic Coatings . . . . .	15
Hard Surface Coatings . . . . .	15
Material Characteristics . . . . .	15
Process Technology . . . . .	17
Thin-Film Manufacturing Equipment . . . . .	19
<b>Summary and Perspective for the Future . . . . .</b>	<b>20</b>
<b>References . . . . .</b>	<b>22</b>
 <b>2. SILICON EPITAXY BY CHEMICAL VAPOR DEPOSITION . . . . .</b>	 <b>26</b>
<i>Martin L. Hammond</i>	
Introduction . . . . .	26
Applications of Silicon Epitaxy . . . . .	27
Theory of Silicon Epitaxy by CVD . . . . .	29
Silicon Epitaxy Process Chemistry . . . . .	31
Commercial Reactor Geometries . . . . .	33
Horizontal Reactor . . . . .	34
Cylinder Reactor . . . . .	34
Vertical Reactor . . . . .	35
New Reactor Geometry . . . . .	35
Theory of Chemical Vapor Deposition . . . . .	36
Process Adjustments . . . . .	38
Horizontal Reactor . . . . .	39
Cylinder Reactor . . . . .	39
Vertical Reactor . . . . .	41
Control of Variables . . . . .	43
Equipment Considerations for Silicon Epitaxy . . . . .	44
Gas Control System . . . . .	44
Leak Testing . . . . .	45
Gas Flow Control . . . . .	46
Dopant Flow Control . . . . .	47
Other Equipment Considerations . . . . .	51
Heating Power Supplies . . . . .	51
Effect of Pressure . . . . .	52
Temperature Measurement . . . . .	53
Backside Transfer . . . . .	55
Intrinsic Resistivity . . . . .	56
Phantom p-Type Layer . . . . .	56

## Appendix B

Defects in Epitaxy Layers . . . . .	56
Haze . . . . .	57
Pits . . . . .	57
Orange Peel . . . . .	57
Faceted Growth . . . . .	57
Edge Crown . . . . .	57
Etch Pits . . . . .	58
Slips . . . . .	58
Stacking Faults . . . . .	58
Spikes and Hillocks . . . . .	58
Shallow Pits . . . . .	58
Safety . . . . .	59
Key Technical Issues . . . . .	59
Productivity/Cost . . . . .	59
Uniformity/Quality . . . . .	62
Buried Layer Pattern Transfer . . . . .	62
Autodoping . . . . .	66
Dopant Transitions . . . . .	69
New Materials Technology for Silicon Epitaxy . . . . .	74
Low Temperature Epitaxy . . . . .	75
Conclusions . . . . .	76
References . . . . .	76
 3. LOW PRESSURE CHEMICAL VAPOR DEPOSITION . . . . .	80
<i>Ronald C. Rossi</i>	
Introduction . . . . .	80
Equipment . . . . .	81
Horizontal Reactor . . . . .	83
Gas Control Systems . . . . .	84
Vacuum Systems . . . . .	84
Process Control Systems . . . . .	85
Vertical Reactors . . . . .	85
Bell Jar Reactors . . . . .	85
Single Wafer Reactors . . . . .	86
Principles of Low-Pressure CVD . . . . .	87
LPCVD Processing . . . . .	88
Polysilicon . . . . .	90
Silicon Nitride . . . . .	95
Low-Temperature Oxide (LTO) . . . . .	100
Other LPCVD Processes . . . . .	106
Tetraethylorthosilicate (TEOS) . . . . .	106
Diacetoxysilane (DADBS) . . . . .	106
Phosphorus-Doped Silicon . . . . .	106
Doped LPLTO . . . . .	107
Tungsten . . . . .	107
Tungsten Silicide . . . . .	108
Semi-Insulating Polysilicon (SIPOS) . . . . .	108
Aluminum and Aluminum Silicon Alloys . . . . .	108

## Appendix B

Goldwasser *et al.*

Application No.: 08/847,967

Boron Nitride. . . . .	108
Summary. . . . .	108
References. . . . .	109
<b>4. PLASMA-ASSISTED CHEMICAL VAPOR DEPOSITION. . . . .</b>	<b>112</b>
<i>V.S. Nguyen</i>	
Introduction. . . . .	112
General Principles . . . . .	113
Nature of Plasma. . . . .	113
Reaction Kinetics in Plasma. . . . .	117
Deposition Mechanism . . . . .	120
Radical Mechanism . . . . .	122
Ionic Mechanism . . . . .	123
The Deposited Films . . . . .	124
Silicon Nitride . . . . .	124
Silicon Oxynitride. . . . .	126
Silicon Oxide . . . . .	128
Silicon Films . . . . .	130
Other Conductor and Semiconductor Films . . . . .	130
Equipment for Plasma Deposition. . . . .	132
Effects of Operating Parameters. . . . .	138
Future Research and Development . . . . .	140
References. . . . .	141
<b>5. MICROWAVE ELECTRON CYCLOTRON RESONANCE PLASMA CHEMICAL VAPOR DEPOSITION . . . . .</b>	<b>147</b>
<i>Seitaro Matsuo</i>	
Introduction. . . . .	147
ECR Plasma Deposition Apparatus . . . . .	148
Divergent Magnetic Field Plasma Extraction. . . . .	150
Deposition Characteristics. . . . .	154
Silicon Nitride Deposition. . . . .	155
Silicon Dioxide. . . . .	159
Ion Incidence Effects. . . . .	159
Material Supply By Sputtering. . . . .	163
ECR Plasma CVD System . . . . .	166
Conclusions . . . . .	168
References. . . . .	168
<b>6. MOLECULAR BEAM EPITAXY: EQUIPMENT AND PRACTICE. . . . .</b>	<b>170</b>
<i>Walter S. Knodle and Robert Chow</i>	
The Basic MBE Process. . . . .	170
Competing Deposition Technologies . . . . .	173
Liquid Phase Epitaxy. . . . .	173
Vapor Phase Epitaxy and MOCVD . . . . .	174
MBE-Grown Devices . . . . .	176
Transistors. . . . .	177
Microwave and Millimeter Wave Devices. . . . .	178

## Appendix B

18	Optoelectronic Devices . . . . .	180
18	Integrated Circuits . . . . .	181
19	<b>MBE Deposition Equipment . . . . .</b>	<b>183</b>
	Vacuum System Construction . . . . .	183
2	Construction Practices . . . . .	183
	Multi-Chamber Systems . . . . .	184
2	Pumping Considerations . . . . .	186
3	Sample Transfer Techniques . . . . .	186
3	Sources . . . . .	186
7	Thermal Evaporation Sources . . . . .	187
0	Electron Beam Heated Sources . . . . .	191
2	Implantation Sources . . . . .	191
3	Gas Sources . . . . .	191
4	Source Shutters and the Source Flange . . . . .	192
4	Sample Manipulation . . . . .	192
6	Sample Mounting . . . . .	192
8	Sample Temperature Control . . . . .	192
0	Sample Rotation Control . . . . .	193
0	System Automation . . . . .	194
2	Performance Parameters . . . . .	194
8	<b>Principles of Operation . . . . .</b>	<b>194</b>
0	Substrate Preparation . . . . .	198
1	III-V Substrate Cleaning . . . . .	198
	Silicon Substrate Cleaning . . . . .	198
	II-VI Substrate Cleaning . . . . .	199
7	Growth Procedure . . . . .	199
	Thermal Transient . . . . .	200
7	Doping Control . . . . .	200
3	Compositional Control . . . . .	201
0	Interrupted Growth . . . . .	203
1	In Situ Metallization . . . . .	203
5	In Situ Analysis . . . . .	204
3	Reflection High Energy Electron Diffraction . . . . .	204
3	X-ray Photoelectron Spectroscopy . . . . .	204
3	Auger Electron and Secondary Ion Mass Spectroscopy . . . . .	204
3	Residual Gas Analysis . . . . .	205
3	Materials Evaluation . . . . .	205
3	Optical Microscopy . . . . .	205
	Hall Effect . . . . .	206
	Capacitance-Voltage . . . . .	206
	Photoluminescence Spectroscopy . . . . .	207
	Deep Level Transient Spectroscopy . . . . .	207
	Safety . . . . .	208
	<b>Recent Advances . . . . .</b>	<b>208</b>
	RHEED Oscillation Control . . . . .	209
	GaAs on Silicon . . . . .	210
	Oval Defect Reduction . . . . .	210
	Chemical Beam Epitaxy/Gas Source MBE . . . . .	212

## Appendix B

Hydride MBE . . . . .	212
Metalorganic MBE . . . . .	212
Superlattice Structures . . . . .	213
Strained-Layer Superlattices . . . . .	213
Superlattice Buffer Layers . . . . .	214
Superlattice Device Structures . . . . .	214
Future Developments . . . . .	214
Production Equipment . . . . .	214
In Situ Processing . . . . .	216
Process Developments . . . . .	217
Ionized Cluster Beam Epitaxy . . . . .	217
Vacuum Chemical Epitaxy . . . . .	217
Irradiation Assisted MBE . . . . .	218
Toxic Gases and Environmental Concerns . . . . .	218
References . . . . .	218
 <b>7. METAL-ORGANIC CHEMICAL VAPOR DEPOSITION: TECHNOLOGY AND EQUIPMENT . . . . .</b>	 <b>234</b>
<i>J.L. Zilko</i>	
Introduction . . . . .	234
Physical and Chemical Properties of Sources Used in MOCVD . . . . .	237
Physical and Chemical Properties of Organometallic Compounds . . . . .	238
Organometallic Source Packaging . . . . .	241
Hydride Sources and Packaging . . . . .	243
Growth Conditions, Mechanisms and Chemistry . . . . .	244
Growth Conditions and Materials Purity . . . . .	245
Growth Mechanisms . . . . .	249
Gas Phase Chemical Reactions . . . . .	251
System Design and Construction . . . . .	252
Leak Integrity and Cleanliness . . . . .	252
Oxygen Gettering Techniques . . . . .	253
Gas Manifold Design . . . . .	254
Reaction Chamber . . . . .	256
Exhaust and Low Pressure MO-CVD . . . . .	260
Future Developments . . . . .	261
References . . . . .	265
 <b>8. PHOTOCHEMICAL VAPOR DEPOSITION . . . . .</b>	 <b>270</b>
<i>Russell L. Abber</i>	
Introduction . . . . .	270
Theory . . . . .	271
Review of Photo-CVD Applications . . . . .	273
Silicon . . . . .	273
Dielectrics and Insulators . . . . .	276
Metals . . . . .	277
Compound Semiconductors . . . . .	279
Miscellaneous . . . . .	280

## Appendix B



Ph to-CVD Equipment . . . . .	280
Commercial Equipment . . . . .	280
Reactor Design . . . . .	282
Summary . . . . .	286
References . . . . .	286
<b>9. INTRODUCTION TO SPUTTERING . . . . .</b>	<b>291</b>
<i>Brian Chapman and Stefano Mangano</i>	
<b>Principle and Implementation of Sputtering . . . . .</b>	<b>291</b>
Introduction . . . . .	291
What Is Sputtering? . . . . .	294
Applications of Sputtering . . . . .	295
Sources of Sputtering 'Bullets' . . . . .	295
Ion Beam Sputtering . . . . .	295
Ions From Plasmas . . . . .	296
Glow Discharge DC Sputtering . . . . .	297
Practical DC Sputtering Systems . . . . .	298
<b>Challenges in Sputter Deposition . . . . .</b>	<b>299</b>
<b>High Rate Sputtering . . . . .</b>	<b>299</b>
DC Magnetrons . . . . .	299
<b>Sputtering of Insulators . . . . .</b>	<b>300</b>
RF Sputtering . . . . .	300
RF Magnetrons . . . . .	301
<b>Reactive Processes . . . . .</b>	<b>301</b>
Reactive Sputter Deposition . . . . .	302
Control of Stoichiometry . . . . .	302
<b>Bias Sputtering . . . . .</b>	<b>303</b>
Properties of Bias Sputtered Films . . . . .	303
Topography Control With Bias . . . . .	304
DC or RF Bias? . . . . .	304
<b>Sputter Deposition Equipment . . . . .</b>	<b>305</b>
Variety of Equipment . . . . .	305
Semiconductor Deposition Equipment . . . . .	306
Static Systems . . . . .	307
Planar Rotation Systems . . . . .	308
In-Line System . . . . .	308
Modules of a Sputter Deposition System . . . . .	308
<b>Etching . . . . .</b>	<b>311</b>
Sputter Etching . . . . .	311
Patterning By Sputter Etching . . . . .	311
Glow Discharge Etching . . . . .	312
Ion Beam Etching . . . . .	312
Limitations of Sputter Etching . . . . .	312
Plasma Etching . . . . .	313
Patterning By Plasma Etching . . . . .	313
Patterning By Lift-Off . . . . .	314
<b>Future of Sputtering . . . . .</b>	<b>315</b>
Sputtering For Step Coverage . . . . .	315

## Appendix B

Sputtering or CVD?	316
Sputter-Assisted Processes	316
Conclusions	317
References	317
<b>10. LASER AND ELECTRON BEAM ASSISTED PROCESSING</b>	<b>318</b>
<i>Cameron A. Moore, Zeng-qu Yu, Lance R. Thompson, and George J. Collins</i>	
Introduction	318
Beam Assisted CVD of Thin Films	319
Conventional CVD Methods	319
Electron Beam Assisted CVD	320
Laser Assisted CVD	320
Experimental Apparati of Beam Assisted CVD	320
Comparison of Beam Deposited Film Properties	322
Laser-Deposited Dielectric Films	322
Laser-Deposited Metallic Films	325
Electron-Beam Deposited Dielectric Films	327
Submicron Pattern Delineation With Large Area Glow	
Discharge Pulsed Electron-Beams	330
Beam Induced Thermal Processes	333
Overview	333
Electron Beam Annealing of Ion-Implanted Silicon	334
Electron Beam Alloying of Silicides	336
Laser and Electron Beam Recrystallization of Silicon on SiO <sub>2</sub>	338
Summary and Conclusions	340
References	341
<b>11. IONIZED CLUSTER BEAM DEPOSITION</b>	<b>344</b>
<i>Isao Yamada, Toshinori Takagi, and Peter Younger</i>	
Introduction	344
Formation of Clusters and Properties of the Cluster	345
Ionized Cluster Beam Deposition Equipment	349
Film Formation Kinetics	351
Film Properties	354
Metals	357
Metal-Insulator-Semiconductor Structures	358
Semiconductors	360
Oxides, Nitrides and Others	361
Conclusions	362
References	362
<b>12. ION BEAM DEPOSITION</b>	<b>364</b>
<i>John R. McNeil, James J. McNally and Paul D. Reader</i>	
Introduction	364
Overview of Ion Beam Applications	364
Categories of Kaufman Ion Sources	365
Operational Considerations	367

## Appendix B

16	Ion Beam Probing . . . . .	367
16	Substrate Cleaning With Ion Beams. . . . .	370
17	Applications. . . . .	373
17	Ion Beam Sputtering . . . . .	373
	Aspects of Sputtering. . . . .	373
18	Advantages/Disadvantages of Ion Beams for Sputtering. . . . .	376
	Aspects of Ion Beam Sputter Apparatus. . . . .	376
	Properties of Ion Beam Sputtered Films. . . . .	379
18	Ion Assisted Deposition . . . . .	380
19	Equipment. . . . .	380
19	Procedures. . . . .	382
20	Examples of Applications of IAD to Optical Coatings. . . . .	383
20	IAD Results. . . . .	383
20	Application Summary . . . . .	390
22	Concluding Comments . . . . .	391
22	References. . . . .	391
25		
27	13. PLASMA AND ELEVATED PRESSURE OXIDATION IN VERY LARGE SCALE INTEGRATION AND ULTRA LARGE SCALE INTEGRATION . . . . .	393
30	Arnold Reisman	
33	Introduction. . . . .	393
34	Plasma Assisted Oxidation Processes . . . . .	396
6	Elevated Pressure Oxidation . . . . .	402
8	Conclusions . . . . .	405
0	References. . . . .	406
1		
4	INDEX . . . . .	409
4		
4		
5		
9		
1		
4		
7		
3		
0		
1		
2		
2		
1		
1		
1		
5		
7		

## Appendix B

Goldwasser *et al.*

Application No.: 08/07,967